THE BUNKER-RAMO CORPORATION

[redacted]

# FINAL SUMMARY REPORT:

## Research Study of Spacecraft and Aircraft Manual Control Systems Theories

30 April 1965

Prepared under Contract No. NASw-869 by
THE BUNKER-RAMO CORPORATION
Canoga Park, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

## Foreword

Under National Aeronautics and Space Administration Contract NASw-869 with The Bunker-Ramo Corporation, Section 3.1.6.3 specified that a final report shall be prepared including a summary of all work performed under the contract and conclusions derived therefrom. The present report is that final summary report.

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# I. SUMMARY

Under the contract schedule of National Aeronautics and Space Administration Contract NASw-869, The Bunker-Ramo Corporation is charged with the responsibility of conducting certain study and research efforts in the area of space craft and aircraft system design, analysis, and synthesis. The general objectives of the study were (1) to synthesize and analyze existing data pertaining to manual control systems, and (2) to evaluate critically facets of manual control system theory wherein insufficient or inconsistent data exist.

Specifically, under the scope of work defined for Contract NASw-869, four major work areas are noted: (1) manual control system theories, (2) performance measurement criteria, (3) pilot re-entry guidance and control, and (4) pilot booster guidance and control. Based on the request of the NASA Technical Monitor, a fifth area was added: (5) survey of Russian literature in manual control and associated areas.

In this final summary report for contract activities the following completed items are noted:

1. Reports Issued. During the contract period the major output of the contract concerned technical Topical Reports. Some eight such reports were issued. Two of these have subsequently been issued as NASA Contractor Reports, and we anticipate additional NASA Contractor Reports appearing after the end of the contract.

2. Presentations. Part of our professional responsibility is the presentation of technical papers before professional societies. During the contract period, six such presentations were made.

3. Published Papers. From the material generated during the contract, three papers were published in outside media with full credit being assigned to NASA support.

4. Monthly Meetings. The contract schedule required that certain monthly technical meetings be held at times and places designated by the NASA Technical Monitor. A total of 22 such meetings were held during the contract period; a short Memorandum describing the content of each meeting is included in Appendix A.

5. Summary of Major Areas. Within the five major areas defined above, a summary has been provided of the major activities within each of the five areas.

## II. REPORTS ISSUED

As noted in Section 3.1.6.1 of the Contract Schedule, the major material output of this program is the technical Topical Report covering the technical work performed under the contract. During the duration of the contract, the following Topical Reports were completed:

Obermayer, R. W., and Muckler, F. A. Modern Control System Theory and Human Control Functions.

Obermayer, R. W., and Muckler, F. A. On the Inverse Optimal Control Problem in Manual Control Systems.

Obermayer, R. W. Simulation, Models, and Games: Sources of Measurement.

Miller, A. B. Pilot Re-Entry Guidance and Control.

Bertone, C. M. A Bibliography of Russian Scientific and Technological Literature in Manual Control Systems and Associated Areas.

Bertone, C. M. A Presentation, Analysis and Comparison of Czechoslovakian Human Engineering Standards with U. S. Equivalents.

Muckler, F. A. Current and Future Trends in Manual Control System Research.

Muckler, F. A. A Survey of Space Flight Experiments for Manned Guidance and Control.

### NASA Contractor Reports

Some of the topical reports listed above were submitted to the NASA Technical Monitor for consideration as subsequent publications in the form of NASA Contractor Reports. To date, two such reports have appeared:

Obermayer, R. W., and Muckler, F. A. On the Inverse Optimal Control Problem in Manual Control Systems. NASA Contractor Report CR-208, April 1965.

Bertone, C. M. A Bibliography of Russian Scientific and Technological Literature in Manual Control Systems and Associated Areas. NASA Contractor Report CR-199, April 1965.

It is our current understanding that additional NASA Contractor Reports will be issued after the termination of the contract based on some of the Topical Reports listed above.

## III. PRESENTATIONS BEFORE PROFESSIONAL SOCIETIES

As has been our custom in the past several years, we have participated extensively in technical presentations before professional societies. The following citations list our presentations over the contract duration.

Obermayer, R. W., and Muckler, F. A. Modern control system theory and human control functions. Fifth National Symposium on Human Factors in Electronics, IEEE, San Diego, 6 May 1964.

Muckler, F. A. Current and future trends in manual control system research. Fifth National Symposium on Human Factors in Electronics, IEEE, San Diego, 6 May 1964.

Muckler, F. A. (Chairman) The use of modelling and projection in simulation. First Systems Engineering Conference, New York Coliseum, New York, 10 June 1964.

Obermayer, R. W. On the inverse optimal control problem in manual control studies. University of Michigan-NASA Working Conference on Manual Control Systems, Ann Arbor, 3-5 December 1964.

Muckler, F. A. (Chairman) Man in the guidance and control loop. 11th Annual East Coast Conference on Aerospace and Navigational Equipment, IEEE, Baltimore, 23 October 1964.

Obermayer, R. W., and Muckler, F. A. Modern optimal control theory and mathematical models of human operator performance. IEEE International Convention, New York, 23 March 1965.

## IV. PUBLISHED PAPERS

As noted in the contract schedule, permission is given to publish in scientific and technical media provided in proper recognition is given to NASA support. The following published papers have appeared with explicit recognition of NASA contractual funding.

Obermayer, R. W., and Muckler, F. A. Modern control system theory and human control functions. Proceedings Fifth National Symposium on Human Factors in Electronics IEEE, pp. 191-210.

Obermayer, R. W. Simulation, Models, and Games: Sources of Measurement. Human Factors, 1964, 6(6), in press.

Obermayer, R. W., and Muckler, F. A. On the inverse optimal control problem in manual control systems. 1965 IEEE International Convention Record, Part 6: Human Factors, pp. 153-165.

No other publications are anticipated for the technical material generated under this contract.

## V. MONTHLY MEETINGS

Under the contract schedule, we have been required to attend certain monthly technical meetings at times and places designated by the NASA Technical Monitor. In general, the purpose of these meetings has been two-fold: (1) to review current activities in the area of manual control systems, and (2) to provide technical consulting services of various NASA manual guidance and control specialists.

During the contract duration, some 22 monthly meetings were held. The place, content, and participants for each of the meetings is described in the Memoranda attached in Appendix A.

## VI. MAJOR WORK AREAS

As noted in the Summary, four major work areas were defined for this contract: (1) manual control system theories, (2) performance measurement criteria, (3) pilot re-entry guidance and control, and (4) pilot booster guidance and control. Based on the request of the NASA Technical Monitor, a fifth area was added: (5) survey of Russian literature in manual control and associated areas. In the following, a discussion is provided of the work performed and the results we obtained.

### 1. Manual Control System Theories

#### Analysis of Optimal Control Theory

One of the major objectives of the present program was to examine modern optimal control theory and to establish the possibility that some, or all, of that theory could be used with respect to manual control system problems.

In our initial optimism, we had hoped that the theory was in a form that would allow ready application to the manual control system problem area. This, in fact, turned out not to be the case. The theory is very new, and in many cases theoretical development is in a state of considerable ferment.

From the theoretical programs under way at the present time, we examined in particular three: (1) Pontryagin's Maximum Principle, (2) Bellman's Dynamic Programming, and (3) Kalman's Solution for Linear Systems. As the study developed, it became apparent that Kalman's work was most promising, and his technique for the inverse optimal control problem seemed most directly applicable to our problem area.

#### Analytic Investigations

Modern control theory and human optimalizing behavior. A very enticing potential of modern control theory is the possibility of describing the conditions under which human tracking performance is optimal. If human tracking behavior can be described as the pursuit of specific performance goals, and if these goals are adequately achieved to permit identification, then specification of the conditions under which human tracking is optimal may lead to an

understanding of the strategies and techniques that the human operator imposes on the tracking task.

Approaches. For a given control task a number of methods exist, under a specified definition of optimality, to derive the control law which will yield optimal performance. The opportunity is therefore presented to allow the calculation of optimal control laws over a matrix of performance criteria, and then compare against descriptions of human behavior to identify the nature of the performance criteria adopted. Such a technique is feasible through the use of high-speed digital computers. Ostensibly, however, a more attractive approach is available. It is feasible, at least theoretically, to invert optimal control theory computations to find directly the performance index optimized by a given control law, rather than the ordinary way, of finding a control law which optimizes given criteria.

Kalman's technique for optimal linear control systems. Kalman's solution applies to linear systems of any order (with possibly time-variable coefficients) where the performance index is expressed in terms of quadratic forms* (quadratic loss functions). Expressed in matrix notation the system equations and the performance index take the following form:

$$\dot{X} = A(t)\,X + G(t)\,u$$

$$J = \tfrac{1}{2}\,X^{T}{}_{(t_f)}\,S\,X(t_f) + \tfrac{1}{2}\int_{t_o}^{t_f}\left[X^{T}QX + U^{T}\,R\,U\right]\,dt$$

Here, x is the state vector, u the control vector, J the scalar performance index, and the others are matrices of constants (possibly time-variable). Kalman requires the matrices S, Q, R to be symmetric, R must have an inverse, and the bracketted quantity must be positive definite. The performance index is composed of the weighting of the state at terminal time ($t_f$), the time-history of the state variables during the intermediate trajectory, and the time-history of the use of control; the relative weighting of each of these factors is determined by the matrices, S, Q and R respectively.

For any system of this quite general form, Kalman asserts that the optimal control law is a linear feedback of the state vector.

$$U = (-\,R^{-1}G^{T}P)X$$

Here the matrix P(t) satisfies a matrix Riccati differential equation:

*With a quadratic form, the terms are weighted cross-products and squares of the state variables; e.g.

$$X^{T}QX = \begin{bmatrix}X_1 & X_2\end{bmatrix}\begin{bmatrix}Q11 & Q12\\ Q12 & Q22\end{bmatrix}\begin{bmatrix}X_1\\ X_2\end{bmatrix} = \begin{bmatrix}X_1 & X_2\end{bmatrix}\begin{bmatrix}(Q11\,X_1 + Q12\,X_2)\\ (Q12\,X_1 + Q22\,X_2)\end{bmatrix}$$

$$= Q11\,(X_1)^2 + 2Q12\,(X_1\,X_2) + Q22\,(X_2)^2$$

$$\dot{P} = PGR^{-1}G^{T}P - PA - A^{T}P - Q$$

$$P(t_f) = S$$

Inverting Kalman's technique. There are a number of characteristics of the manual control tasks for which mathematical models are available, which permit working Kalman's technique backwards. These are:

1. The human operators are tracking continuously throughout an experimental trial without giving any particular consideration for conditions terminating the trial. They are not trying to achieve any particular state at the end of the trial (at least they are given no instructions to this effect). This permits matrix S to be set to zero.

2. The control law is specified as a constant relation (since the human operator model has constant coefficients): $U = -KX$ Under these conditions, the result is given by the steady state solution of the Riccati matrix differential equation. Under this condition $\dot{P} = 0$.

Kalman's solution, in the form shown here, is only applicable if the manual control task corresponds to the regulator problem. An explicit nontrivial result for the servomechanism problem is not currently possible.

With the above provisions, one is left with only the task of solving for performance matrices R and Q, and the Ricatti differential equations becomes an algebraic equation ($\dot{P} = 0$). For a given constant control system, the control law is known; if the feedback gains are inserted in the above equations one may then solve a system of simultaneous algebraic equations for the unknown elements of the performance matrices. It should be pointed out here that it is not possible to write a sufficient number of equations to solve for all unknown elements of the performance matrices. It is necessary to normalize with respect to the weighting on the control input ($R = 1$), and even then is only possible to solve for n elements of the Q matrix (where n is the order of the total system). In the following this means that the Q matrix weighting the state variables takes on the following form:

$$Q = \begin{bmatrix} Q_{11} & \cdot & \cdot & 0 \\ 0 & Q_{22} & & \cdot \\ \cdot & & \cdot & \cdot \\ 0 & \cdot & \cdot & Q_{nn} \end{bmatrix}$$

While other variations may be reasonable (however, Q must be positive definite), this selection weights only the squares of the state variables, assuming no weighting of cross-products of the state variables (i.e., no requirement that the state variables are correlated).

A Computer Investigation

To investigate the suitability of inverse optimal control techniques to the study of human tracking behavior, the inverse technique suggested by Kalman's solution was programmed for a high-speed digital computer. The basic approach

was to program for digital computer computation and compute the optimal performance indices corresponding to existing models of human operator tracking.

The technique outlined in the previous section produces two computational problems: first for a given control system, a system of simultaneous linear algebraic equations must be set up, and then the system of equations must be solved for the coefficients of the loss functions. Correspondingly two basic programs were written in the FORTRAN computing language, with slight changes necessary for different system dynamics.

The data were taken from McRuer and Krendel (1957) and Adams (1963). In the case of the McRuer-Krendel data (i.e., Russell, Franklin Institute and Elkind data) the lag term is ignored for computer computation. The Adam's model incorporates equal roots in the denominator, yielding an ambiguous partial fraction expansion; in this case, the computer was set up with unequal roots, separated slightly, and a number of runs were made with decreasing difference between roots to assure that the solutions were well-behaved.

Results. The results of the digital computer programs are shown in Tables 1, 2, and 3. As the problem is defined, the result is given in terms of the weighting of the state variables in the performance index, which depend totally on the matrix Q. The number of state variables and hence the order of Q depends upon the order of the total man-machine system (human operator dynamical model + controlled element dynamics).

Discussion. Through the above analytic activity a method for computing the basis for human optimal behavior was developed. Although some modes of behavior may be beyond the implicit definitions of optimal performance, and the technique requires full and unabbreviated mathematical models of operator control, for most cases a weighing matrix can be computed which describes a basis under which the control was optimal. Although this activity was quite exploratory, it appears that the technique used may provide a useful tool for the study of human optimalizing behavior.

Examination of the bases for optimal control theory point up that the concept of "optimal" control is somewhat elusive and at odds with the usual concept of the optimum. Optimal control theory initially assumes that the definition of optimality is given, and allows a broad range of possible definitions. When one attempts to invert the process to find the conditions under which a given control system is optimal, he finds that the given system may simultaneously optimize on various criteria, and that some of the criteria optimized may not be "good" in the sense of normal control engineering objectives. The theoretical objectives implied in the study of human optimalizing behavior deserve full and detailed study.

TABLE 1

POSITION CONTROL: FIRST ORDER SYSTEM ELKIND'S DATA

| COND. | K | $1/T_I$ | Q |
|---|---|---|---|
| R .96 | 2.113 | 3.65 | 115.7 |
| R1.6 | .9333 | 3.77 | 38.9 |
| R2.4 | .7079 | 1.885 | 6.82 |
| F1 | 3.350 | 1.13 | 22.9 |
| F2 | 17.78 | 0.314 | 346. |
| F3 | 44.67 | 0.1885 | 74.3 |
| B1 | 2.818 | 4.78 | 311. |
| B2 | 1.189 | 5.03 | 96.1 |
| B3 | 0.8912 | 12.6 | 409. |
| B4 | 0.9660 | 12.6 | 456. |
| B5 | 3.589 | 1.88 | 71.0 |
| B6 | 7.674 | 1.00 | 74.1 |
| B9 | 1.047 | 12.6 | 507. |
| B10 | - | 2.82 | - |

TABLE 2

SECOND AND THIRD ORDER SYSTEMS

| INVESTIGATOR | K | $1/T_I$ | $1/T_N$ | $1/T_L$ | Q11 | Q22 | Q33 |
|---|---|---|---|---|---|---|---|
| Franklin: | 100 | .04 | 1.5 | .5 | + 36.720 | + 168.96 | |
| | 40 | .11 | 4.55 | 2.0 | + 420.84 | + 153.45 | |
| | 1.5 | .2 | 11.0 | 3.0 | + 25.410 | + 19.250 | |
| Elkind: | 53.09 / 34.5db | .22 | 1.885 | | + 503.14 | - 44.040 | |
| | 37.58 / 31.5db | .314 | 6.22 | | + 5674.3 | - 146.80 | |
| | 13.34 / 22.5db | .785 | 12.3 | | +19076.7 | - 257.60 | |
| | 5.623 / 15.0db | 1.73 | 30.3 | | 117813. | - 589.60 | |
| | 14.45 / 23.2db | .88 | 17.8 | | +58301. | - 452.60 | |
| | 2.818 / 9.0db | 3.14 | 6.28 | | + 5279. | - 111.14 | |
| Russell: | 17.7 | 0.1 | | 0.68 | 3.5049 | + 9.0045 | |
| | 7.55 | 0.13 | 25 | 0.9 | + 3053.6 | +6158.1 | -109.2 |
| | 10. | 3 | 14 | 2 | + 8467.2 | +2688.0 | - 84.000 |

TABLE 3

$2/_S$ DYNAMICS ADAM'S DATA

| $C_1$ | $C_2$ | A = B | $Q_{11}$ | $Q_{22}$ | $Q_{33}$ |
|---|---|---|---|---|---|
| 32.2 | 2.27 | 4.54 | +5345.7 | +1037.1 | -64.401 |
| 23.1 | 3.03 | 5.0 | +4902.5 | + 288.88 | -46.203 |
| 8.61 | 1.492 | 3.03 | + 165.26 | + 76.564 | -17.220 |
| 10.22 | 2.324 | 3.45 | + 564.69 | + 20.004 | -20.441 |
| 14.02 | 0.571 | 2.0 | + 64.151 | + 244.70 | -28.040 |
| 24.6 | 2.324 | 3.45 | +3269.8 | + 401.90 | -49.201 |
| 16.0 | 1.492 | 3.03 | + 570.31 | + 260.52 | -32.000 |
| 5.93 | 2.70 | 4.0 | + 256.86 | - 31.226 | -11.860 |

The results obtained in the above analytic activity do not point to consistent optimalizing behavior. However, upon further examination of the results one is inclined to say that the human operator may be capable of optimizing with regard to various criteria, and that the scatter of results may indicate differences in human goals and strategies rather than the ability of the operators to produce equivalent results. Our experimental methodology is lacking in this respect for the subjects in our experiments are usually either given vague instructions and/or are experienced control engineers operating on unreported criteria. Further study is recommended to improve our experimental methodology, and what is more critical, to point up design techniques for the control and aiding of specific bases for human optimalizing control behavior.

Survey of Current Technology

Of part of our general contract objective to point out areas of deficiency in the manual control system area, a survey was conducted on current and future trends in manual control system research.

Based on an assessment of past and present theoretical, experimental, and methodological work in the area, four distinct problem domains were examined. First, the most exciting and active area in manual control research today is the development of quantitative theory; this should be the major future research area. Second, there still appears to be, after thirty years of empiricism, a great deal of detailed ignorance about the fine, or microstructure, details of human behavior in control systems; the experimental strategy of the past has not particularly helped in reducing our uncertainty. Third, the technology and practice of the development, simulation and test of manual control systems seems to be on very favorable grounds; we have the tools, the methods, and the experience to develop, simulate and test hardware. Fourth, the only basic technical problem we have yet to overcome in the design of manual control systems is in the allocation of control function; this problem has seemed to be most intractable - and most essential for solution.

It was our hope that during the execution of this contract we might, as a byproduct, contribute some theoretical steps in solving the allocation of control function problem. Our hopes were not justified. Further, we find our

apprehension about this problem does not seem to be shared by many of the control system specialists with whom we have exchanged informal discussions. These specialists do not have any solutions, but do not appear to be as concerned with the problem as we are.

## 2. Performance Measurement Criteria

### Optimal Control Theory

In the previous discussion of our approach to modern optimal control theory and manual control, much was made of the problem of specifying the performance index and the performance matrices. The importance of so doing explicitly is central to the application of that theory.

One of the major problems, it appears to us, in the manual control system literature is the methodological one of performance measurement. There are no standardized sets of measures by which specialists evaluate either man-machine system performance or human operator performance. Even quantitative theory in this area has been little help since a minimum error term has generally been taken as the output criterion. Such a score has also minimum information about how the measure was generated.

In design and hardware evaluation, such measures may be acceptable. From the measurement standpoint, either one of two methodological criteria are often dominant. First, we may wish merely to know if the performance measure is within certain boundary conditions. Second, we may wish only to know if a difference exists between conditions. In either case, this is not very sophisticated measurement, but it is probably adequate for the information needed.

If, however, we are concerned with the fine structure of human controller behavior considerably more attention must be given to meaningful measurement of operator performance. One of the advantages of modern control theory as we are using it is that it forced the measurement of the fine structure of control behavior.

### Simulation and Measurement

Since manual control system simulation is an important and reasonably accepted tool in the design of manual control systems, we prepared a specific report on the general topic of simulation, models, and games and the measurement appropriate to them.

Any simulation, model, or game may be considered to be an analogy. They resemble in some way something else about which information is desired. We may, therefore, measure an analogy instead of the real-world object. The critical dimensions of the analogy are the level of abstraction and the fidelity of simulation to the real-world object. However, if the object is to measure, the most critical aspect is the validity of measurement. Unfortunately, validity is not always a practical concept. Since the objective of measurement is to derive information, several classes of simulation studies were analyzed with respect to information objectives in an attempt to derive some basic criteria for measure selection.

## 3. Pilot Re-Entry Guidance and Control

As part of our interest in this problem area, it appeared that a statement of the current knowledge on pilot re-entry capabilities and limitations would be useful. Accordingly, a report was prepared examining the current literature.

In that report some of the problems confronting the pilot during a manually controlled re-entry were considered as well as some of the areas where additional research could most profitably contribute to a more complete knowledge of manual control. The relationship of re-entry vehicle configuration and the nature and severity of manual control maneuvers was discussed in terms of the energy available to control the vehicle and in terms of the display-control relationships as they relate to the functions performed by the human operator.

The importance of training through simulation was stressed, and some of the areas where additional simulation studies are needed was pointed out. It was shown that the problem of escape continues to be a critical area which requires considerable effort if a reliable solution is to be attained.

With regard to future needs, it was point out that simulation studies will continue to be one of the most important and essential vehicles for research into manual control problems and that many more studies of the basic behavioral components of manual control are needed in order to develop more complete models of the human control process. Finally, several articles were thoroughly summarized which are representative of the research now being carried out concerning manual control during re-entry.

## 4. Pilot Booster Guidance and Control

This topic was included in the original work statement so that the NASA Technical Monitor might take advantage of our considerable past experience in the area if technical consultation was desired within the NASA. During the contract period, a very limited amount of such consulting services was required.

Two contacts were made with NASA specialists during the contract period. On 9-12 December 1963, F. A. Muckler consulted with guidance and control specialists at the Manned Spacecraft Center in Houston (see Appendix A, Monthly Meeting No. 2). On 30-31 January 1964, F. A. Muckler consulted with guidance and control specialists directly investigating pilot booster control at the NASA Marshall Spaceflight Center in Huntsville (see Appendix A, Monthly Meeting No. 4).

## 5. A Survey of Russian Literature

Based on the interest of the NASA Technical Monitor, we added a fifth area of study within the contractual scope of work. Our objective was to survey Russian scientific and technological literature in manual control and associated areas.

A report was prepared and submitted in this area. Some 917 documents were reviewed in the following areas:

1. Human engineering (manual control systems)
2. Airborne flight displays and flight control techniques
3. Pilot, aircraft, and space vehicles
4. Manned flight simulators
5. Theory of control systems
6. Air traffic control
7. Psychology (as applied to human engineering)
8. Other manual control systems (e.g., submarines, cars, etc.)

Wherever possible, American source information for the cited references was given.

Consideration was given to the Russian scientists who seem to be generating most of the current material, the institutes that are producing this material, and the specific media in which information is appearing. A number of interesting points were uncovered:

1. Very little has been written by Americans concerning Soviet work in the areas of interest.

2. A wealth of information concerning the work of Soviet scientists is available in this country.

3. Translation services should be expanded, and specific recommendations were made to the NASA Technical Monitor.

4. Manual control reports were limited, at least as to material being reported in the open literature. Information on automatic control systems is, however, readily available in very large quantities.

5. The area of human engineering seems well documented. Prior to 1962 the term "human engineering" was not found although articles pertinent to the field were found dating back to 1896. After 1962, human engineering reports increased at a very high rate.

## Contract Personnel

During the duration of contract NASw-869, the following technical specialists contributed to technical activities:

1. Richard W. Obermayer
2. Carmen M. Bertone
3. Albert B. Miller
4. Frederick A. Muckler

# APPENDIX A

## Monthly Meeting Memoranda

# M E M O R A N D U M

6 December 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 1, 4 December 1963

Participants: Mr. Robert W. Taylor, NASA Technical Monitor
F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D.C.

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The major purpose of this meeting was two-fold: (1) a review of the reports generated under Contract NASw-718, and (2) a preliminary review of the major contract activities under Contract NASw-869.

1. Under Contract NASw-718, three reports were generated including the topics of a summary of the state of the art in manned booster guidance and control, a review of performance measurement in flight simulation studies, and a critical review of the literature on the effects of control system lags on man-machine system performance. The main conclusions of each report were discussed.

2. As had been previously agreed, the technical activities of Contract NASw-869 are to be conducted under four major headings: (a) modern control system theory and manual control systems, (b) development of standardized criteria for man-machine systems performance measurement, (c) continuation of efforts on manned booster guidance and control, and (d) initial efforts into the area of piloted space vehicle re-entry guidance and control.

It was also agreed that we would be available for short-term technical consulting services to specialists at the various NASA research centers as requested in those areas where our past experience might be of value.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

15 December 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 2, 9-12 December 1963

Participants: Dr. R. B. Voas, Manned Spacecraft Center
Capt. J. Loftus, MSC, Project Apollo
Mr. R. Chilton, MSC, Guidance and Control Division
Mr. D. Cheatham, MSC, Guidance and Control Division
Mr. J. Bilodeau, MSC, Crew Operations Division
Dr. W. Fedderson, MSC, Space Medicine Branch
Dr. F. A. Muckler, Martin Company

Place: NASA Manned Spacecraft Center, Houston, Texas

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The major purpose of this meeting was a reciprocal exchange of information on current MSC technical problems and our current technical programs. Of particular interest was the approach of MSC to manual control system design. Three major groups were contacted.

1. Dr. Robert B. Voas and Dr. W. Fedderson represent the major human engineering efforts at the MSC. It was noted that their current programs are not directed toward manned guidance and control problems, but rather to other major life support and human engineering areas. This is not due to lack of interest or recognition but rather to the fact that they do not have the technical capability to staff such types of efforts.

2. Mr. R. Chilton and Mr. D. Cheatham, of the Guidance and Control Division, are primarily responsible for all manned flight simulation work conducted at MSC. Although in the process of moving to the new MSC site, they are attempting to generate an extensive manned flight simulation program. This group represents our major future technical contract at MSC.

3. Capt. J. Loftus and Mr. J. Bilodeau are concerned with crew operations and particularly crew training for Project Apollo. Very extensive flight simulation facilities are being constructed for Apollo astronaut training. Of note at this time is the technique for visual projection display systems, an extremely difficult and important simulation problem area.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

17 January 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 3, 15 January 1964

Participants: Mr. Robert W. Taylor, NASA Technical Monitor
Dr. F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D. C.

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The purpose of this meeting was a routine review of current contract activities under Contract NASw-869. Under our current schedule, we are concentrating heavily on two of the four major technical areas at this time:

1. The formal application of modern control theory to manual control system problems is of major importance. At the present time, the work is essentially in the character of a detailed and critical feasibility study to uncover the formal theoretical bridges between modern control theory and the applied problems of manual control system design.

2. Interest in manual pilot modes of guidance and control for re-entry is of more than research concern. We feel that it is time for a thorough and critical review of our current knowledge in this area and particularly for some plan for creative research. In our approach to the problem, we are concerned with the problem of landing a manned spacecraft on any large land body. Further, there exists the possibility of a formal bridge between modern control theory defining "optimal" trajectory processes and the particular mechanization of automatic, semi-automatic, and manual modes of guidance and control.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

2 February 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 4, 30-31 January 1964

Participants: Mr. Robert W. Taylor, NASA Technical Monitor
Dr. W. Haussermann, Director Astrionics Laboratory
Mr. J. George, Flight Dynamics Branch
Mr. Robert Gunderson, Flight Dynamics Branch
Dr. F. A. Muckler, Martin Company

Place: NASA Marshall Spaceflight Center, Huntsville, Ala.

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The specific purpose of this meeting was a technical review of the current state of the art of pilot booster guidance and control. Current NASA research on this problem is directed through a Joint NASA Steering Committee with prime technical responsibility through the Marshall Spaceflight Center at Huntsville.

Our own recent summary of the technical status of this area was reviewed in discussion. I presented what I believe to be the most reasonable statements that can be made at this time about potential pilot contributions to large space booster guidance and control. We discussed at length the technical problems associated with the introduction of the pilot into the guidance and control loop of current and forthcoming man-rated boosters. Some recent research on piloted booster performance was examined. An exceptionally clever technical approach was made to the problem of filtering the pilot's control output to avoid certain frequency responses that could elicit dominant structural bending mode responses. This finding is consistent with the point of view developed at the Naval Research Laboratory which has stressed the elimination of "noise" from the human controllers output. The superiority of control filtering over display filtering was somewhat surprising. From a design standpoint it is usually less costly to provide display rather than control filtering. But in this particular application problem the necessity of eliminating certain human controller responses must apparently require specific output filtering.

On a question of general research strategy to this entire area, it is my opinion that a somewhat more structured approach to the problem is in order. To date, the research work (including our own) has been piece-meal and specific. Considering the potential importance of this manual control system problem (and noting particularly the domain of recoverable boosters) a broader based technical approach is in order.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

10 February 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler and R. W. Obermayer

Subject: Contract NASw-869, Monthly Meeting No. 5, 4-7 February 1964

Participants:
Mr. W. H. Phillips, NASA Langley Research Center
Mr. J. Whitten, LRC
Dr. R. T. Saucer, LRC
Mr. A. Vogeley, LRC
Mr. J. J. Adams, LRC
Mr. Robert W. Taylor, NASA Headquarters
Dr. J. I. Elkind, NASA Research Advisory Committee
Mr. R. W. Obermayer, Martin Company
Dr. F. A. Muckler, Martin Company

Place: NASA Langley Research Center, Hampton, Virginia
NASA Headquarters, Washington, D. C.

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The purpose of this meeting was an introductory exchange of information on current manned flight research programs underway at Langley Research Center and our own contract activities in the manual control system area. An extended tour was given of the flight simulation facilities and programs currently under way at Langley Research Center including fixed-based and dynamic rendezvous simulation. The Lunar Landing Facility was also visited.

Of considerable interest was a preliminary discussion on the desirability and feasibility of extending work in the human performance area. The nature of the work, the kinds of facilities needed, and particularly the kinds of technical specialists necessary, were examined at some length. In our opinion, it would be desirable in the long run for some centralization of this effort for the NASA. A "critical mass" of resources would be, perhaps, more productive than the current strategy of decentralized research. However, complete centralization is not technically or managerially desirable.

The final day (7 February 1964) was spent at NASA Headquarters, Control and Stabilization Division, discussing the NASA current approach to human performance research, specifically as it pertains to guidance and control tasks.

R. W. Obermayer
Richard W. Obermayer

Frederick A. Muckler
Frederick A. Muckler

M E M O R A N D U M

29 February 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, C. W. North, Jr.

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 6, 27-28 February 1964

Participants: Mr. C. H. Gould, NASA Director Control and Stabilization Division
Mr. R. Bohling, NASA
Mr. C. Janow, NASA
Dr. Stanley Deutsch, NASA Biotechnology and Human Research
Mr. Robert W. Taylor, NASA Technical Monitor
Dr. F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D.C.

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The purpose of this meeting was a routine exchange of information on current contract activities under NASw-869. Extended discussions were held on the proposed technical activities during the second quarter of the contract period with respect to interactions with the NASA Research Centers. It has been proposed that additional support on the manned booster guidance and control problem be given to both Marshall and Ames. Following the first of April, a trip will be made to the Langley Research Center to continue our technical discussions with appropriate technical personnel at that Center (see Monthly Meeting No. 5).

A brief discussion was held with Dr. Stanley Deutsch, NASA Biotechnology and Human Research, on communality of ideas, concepts, and programs.

At the present time, we anticipate that among our other contractual outputs, we will produce by the end of the contract period, six topical technical reports. The detailed outline of the first - "Modern Control System Theory and Human Control Functions" - will be presented orally to the NASA Technical Monitor at a date after 1 April 1964 mutually agreeable to both.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

19 March 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, E. W. Ritter

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 7, 17 March 1964

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. C. Janow, NASA Headquarters
Dr. J. Lasalle, RIAS
F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D. C.

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The purpose of this meeting was a routine exchange of information on current activities in modern control theory and related activities under NASw-869. Dr. Lasalle discussed the current status and possible future activities of his mathematics group on the underlying theoretical work on generalized control theory. Some of the problems of relating theory to both automatic and manual control were reviewed.

It is sometimes difficult for many to understand that current theory cannot be expected to have immediate hardware application. It seems even more difficult for many to understand that theoretical research of today is for future hardware applications. To expect a concurrent payoff is somewhat akin to be expecting to reach a destination while still travelling toward it.

Frederick A. Muckler

Frederick A. Muckler

M E M O R A N D U M

21 March 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, E. W. Ritter

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 8, 19 March 1964

Participants: Mr. C. H. Gould, NASA Headquarters, Electronics and Control
Dr. S. Deutsch, NASA Headquarters, Biotechnology
F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D. C.

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Two technical areas were covered in discussions held during this meeting: (1) current status of activities in the manned booster area, and (2) current status of manual system simulation in the NASA. Both of these areas were discussed relevant to future programs including the study of manned recoverable boosters and simulation for long-duration orbital manned space stations.

1. Under advanced planning the concept of manned recoverable boosters is perhaps one of the most promising and interesting of future programs. One of the major problems is the potential contribution of the crew to recoverable booster flight. In the opinion of the undersigned technical activity at present should be directed toward analytic study of potential tasks within the framework of current vehicle concepts.

2. The objective of the long-duration space station is to collect certain vitally needed information about man's performance in sustained space flight. Prior ground simulation is essential to an effective program fulfilling training checkout and test for inflight research, generating data base, and for exploring certain flight safety items.

Perhaps the one point in common to these two activities is the necessity for careful planning and study prior to research and/or test programs either in simulation or inflight. The maximum information for the least cost can only be achieved if the general and specific goals of each program are carefully delimited in advance.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

2 April 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, E. W. Ritter

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 9, 30 March 1964

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. R. W. Taylor, NASA Headquarters
F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D. C.

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The purpose of this meeting was a routine exchange of information on current activities under NASw-869. Most of the discussion concerned work on the specific topic of the applications of modern control theory to manual control theory and applications to aircraft and space vehicle concepts, design, and development.

Since the NASA Technical Monitor (Mr. Taylor) had not been present at the two previous meetings, the material covered in these past meetings was reviewed with additional discussion. With respect to the general problem of physical simulation of manual systems (aircraft or spacecraft), the question again arose as to the lack of specific methodological rules as to where and when physical simulation should be used in the design and development process. Some rational way of deciding the tradeoff between the expenditure of resources (time, money, facilities, people) and the amount of information required would be desirable.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

28 April 1964

To: Mr. V. Kloster

cc: Messrs. R. W. Obermayer, S. G. Hasler, E. W. Ritter

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 10, 28 April 1964

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. R. W. Taylor, NASA Headquarters
Mr. R. Bohling, NASA Headquarters
Mr. C. Janow, NASA Headquarters
Dr. F. A. Muckler, Martin Company

Place: NASA Headquarters, Washington, D. C.

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The major purpose of this meeting was to deliver, as required by the contractual agreement, the detailed outline and summary of proposed Topical Report No. 1: "Modern Control System Theory and Human Control Functions". This report covers the relationship between certain critical aspects of modern optimal control theory and the problem of the allocation of human control functions in aircraft and spacecraft.

It was recommended that two final topical reports be generated from this basic material. The first is a summary statement for a more generalized technical audience introducing them to the relationships between modern control theory and manual control theory and hardware development. The second is a detailed technical report specifically for specialists in the area of manual control.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

7 May 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter

From: R. W. Obermayer and F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 11, 5 May 1964

Participants:
Mr. R. W. Taylor, NASA Headquarters
Mr. J. J. Adams, NASA Langley Research Center
Mr. G. G. Frost, USAF 6570th AMRL
Mr. D. T. McRuer, Systems Technology, Inc.
Dr. C. R. Kelley, Dunlap and Associates, Inc.
Dr. R. O. Besco, Hughes Aircraft Co.
Dr. J. L. Nevins, MIT Instrumentation Laboratory
Dr. J. I. Elkind, Bolt Beranek and Newman, Inc.
Dr. Thomas B. Sheridan, MIT
Mr. R. J. Wasicko, Systems Technology, Inc.
Dr. G. A. Bekey, UCLA
Dr. R. W. Pew, University of Michigan
Dr. R. M. Howe, University of Michigan
Mr. John Senders, Bolt Beranek and Newman, Inc.
Dr. L. G. Summers, TRW Space Technology Laboratory
Dr. F. A. Muckler, Martin Company
Mr. R. W. Obermayer, Martin Company

Place: San Diego, California

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At the IEEE Fifth National Symposium on Human Factors in Electronics (5-6 May 1964; San Diego), the presence of many of the specialists working in the area of manual control made it convenient to hold an informal working session to discuss what specialists are currently doing and what they are planning for the future. The undersigned discussed briefly our current work on modern control theory and manual control functions.

R. W. Obermayer
Richard W. Obermayer

Frederick A. Muckler
Frederick A. Muckler

# M E M O R A N D U M

1 July 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, F. A. Muckler

From: R. W. Obermayer

Subject: Contract NASw-869, Monthly Meeting No. 12, 16-17 June 1964

Participants: Mr. R. W. Taylor, NASA Headquarters
Mr. C. H. Gould, NASA Headquarters
Mr. R. W. Obermayer, Bunker-Ramo

Place: NASA Headquarters, Washington D. C.

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Three technical areas were discussed during this meeting:

1. An informal oral progress report was presented on the continuation of the modern control theory work and the computer studies. The earlier contract efforts in modern control theory suggested several logical areas for continuation. The successes and problems encountered in following these lines of exploration were discussed.

2. Problems in manual control during approach and landing of high-performance vehicles were discussed.

3. Possible classifications of mathematical descriptions of the human operator of manual control systems were suggested and discussed.

R. W. Obermayer

Richard W. Obermayer

# M E M O R A N D U M

15 July 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 13, 6-7 July 1964

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. R. W. Taylor, NASA Headquarters
Dr. J. Elkind, Bolt, Beranek and Newman, Inc.
Mr. Ezra Krendel, The Franklin Institute
Dr. F. A. Muckler, Bunker-Ramo

Place: NASA Headquarters, Washington, D. C.

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1. The initial purpose of this meeting was to present to the NASA Technical Monitor the technical outline of a proposed topical report, "Pilot Re-Entry Guidance and Control". The report is designed to cover the current state of the art with respect to manual control modes for re-entry vehicles.

2. On 7 July, the undersigned met with Col. Gould, Mr. Taylor, and two other members of the NASA Research Advisory Committee on Control, Guidance and Navigation to discuss: (1) current NASA efforts in the area of manual guidance and control, (2) future trends in this area, and (3) current strengths and limitations of NASA technical efforts. The other two committee members are Dr. Elkind and Mr. Krendel. Of particular interest was the possible efforts that could be made by the three committee members present in supporting the activities of the committee in general.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

10 September 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter

From: F. A. Muckler and R. W. Obermayer

Subject: Contract NASw-869, Monthly Meeting No. 14, 2 September 1964

Participants: Mr. C. H. Gould, NASA Headquarters

Place: The Bunker-Ramo Corporation, Canoga Park, California

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Mr. C. H. Gould, Director of the Control and Stabilization Division, NASA Headquarters, under whose direction Contract NASw-869 visited technical personnel and facilities at The Bunker-Ramo Corporation. The following activities were completed:

1. The current technical activities under Contract NASw-869 were reviewed and critically examined.

2. Mr. Gould met with Mr. A. P. Stern, Director of Engineering, and Mr. S. G. Hasler, Manager of the Systems Effectiveness Department, to discuss current Bunker-Ramo programs of possible interest to Mr. Gould.

3. A general review of facilities and programs were presented to Mr. Gould. This included: (1) the FAA TALS all-weather landing simulation program, (2) display development at Bunker-Ramo, (3) solid state and thin-film developments, (4) automatic mapping programs, (5) anachoic chamber, and (6) human factors laboratories.

F. A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

1 November 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 15, 21 October 1964

Participants: Mr. R. W. Taylor, NASA Headquarters

Place: NASA Headquarters, Washington, D. C.

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The following technical areas were discussed in this meeting:

1. Further evaluations were examined as to the applicability of modern optimal control system theory to manual control systems. Particular attention was given to the inverse optimal control problem.

2. A review was made of the current plans for submittal of topical technical reports.

3. Future theoretical and experimental possibilities for the application of modern control system theory were examined.

4. An informal review was held of the research strategies currently employed in the manual control system area.

5. Plans were made for the presentation to be delivered at the joint University of Michigan-NASA Working Conference on Manual Control Systems, Ann Arbor, 3-5 December 1964.

F. A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

15 November 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, F. A. Muckler

From: R. W. Obermayer

Subject: Contract NASw-869, Monthly Meeting No. 16, 4-6 November 1964

Participants: Dr. George Kovatch, Electronic Research Center, NASA
Mr. E. Hilborn, Electronic Research Center, NASA
Dr. J. Elkind, Bolt, Beranek and Newman

Place: Electronic Research Center, NASA
Boston, Massachusetts

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The principal purpose of this trip was to consult with members of the newly formed Electronic Research Center of the NASA with regard to relevant topics in manual control systems. The meetings took place over the course of three days and at three places: (1) the 18th Annual Northeast Electronics Research and Engineering meeting, (2) the NASA Electronic Research Center, and (3) at Bolt, Beranek, and Newman - all in Boston Massachusetts.

During this time, the state of the art of manual control theory and methodology was thoroughly discussed. In particular, mathematical models of the human operator and simulator research were emphasized, together with requirements for associated facilities and equipment. The discussion of these items continued at BB&N with Dr. Elkind, with the emphasis there on mathematical models and optimal control theory, and a complete demonstration of BB&N experimental and computer facilities.

R. W. Obermayer

Richard W. Obermayer

M E M O R A N D U M

3 December 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, and R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 17, 24 November 1964

Participants: Mr. R. W. Taylor, NASA Headquarters

Place: NASA Headquarters, Washington, D.C.

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The following technical subjects were discussed at this meeting:

1. The topical draft report on "A Bibliography of Russian Scientific and Technological Literature in Manual Control Systems and Associated Areas" was reviewed.

2. The topical report draft on "Simulation, Models, and Games: Sources of Measurement" was critically reviewed.

3. Some discussion was held on the presentation for the University of Michigan meeting in Ann Arbor for 3-5 December 1964.

4. The general and particular problem areas in the field of man-computer relationships were discussed at length.

F. A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

15 December 1964

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, and F. A. Muckler

From: R. W. Obermayer

Subject: University of Michigan-NASA Working Conference on Manual Control Systems; Monthly Meeting No. 18, 3-5 December 1964

Participants: R. W. Taylor, NASA Headquarters
Specialists in Manual Control Systems

Place: University of Michigan, Ann Arbor, Michigan

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Approximately 73 technical specialists in manual control systems met at the University of Michigan to discuss a broad range of problems in human operator control. The meetings held over the period of 3-5 December 1964, consisted of presentations by the majority of the attendees - resulting in a series of highly intensive sessions. The topics discussed ranged over theory, models, measurement, applications, and techniques. As many said, it was "...a chance to see it all at once."

As a part of these meetings, the writer discussed current activities in the applications to manual control of modern control theory, review of the Russian literature in manual control, and problems in the study of pilot eye movements. Preliminary copies of the report, "On the Inverse Optimal Control Problem in Manual Control Studies", were made available.

R. W. Obermayer

Richard W. Obermayer

# M E M O R A N D U M

18 December 1965

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, and R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 19, 11 December 1964

Participants: Mr. R. W. Taylor, NASA Headquarters

Place: NASA Headquarters, Washington, D. C.

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The following items were discussed during this meeting:

1. The general and particular results obtained during the joint University of Michigan-NASA Working Conference on Manual Control Systems held at Ann Arbor, 3-5 December 1964.

2. The technical content of the topical report draft, "On the Problem of Inverse Optimal Control" was reviewed.

3. The general work schedule for the remainder of the contract was reviewed.

4. Some discussion was given to the proper distribution of the topical report surveying the Russian literature on manual control systems.

F. A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

28 January 1965

To: Mr. V. Kloster

cc: Messrs. S. G. Hasler, E. W. Ritter, and R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 20, 25 January 1965

Participants: Mr. R. W. Taylor, NASA Headquarters

Place: NASA Headquarters, Washington, D. C.

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The following items were discussed during this meeting:

1. Since funds were still remaining under the original contract, a request was made for an additional no-cost time extension to cover the period of 2 February 1965 to 2 May 1965.

2. The final topical report on "Simulation, Models and Games: Sources of Measurement" was thoroughly discussed.

3. Some discussion was given to on-line data analysis of performance measurement in manual control system studies.

4. The general problem of the correlation of handling qualities with objective performance measures was again raised.

F. A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

12 March 1965

To: Mr. S. G. Hasler

cc: Messrs. E. W. Ritter and R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 21, 9 March 1965

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. R. Winblade, NASA Headquarters
Dr. F. A. Muckler, Bunker-Ramo

Place: NASA Headquarters, Washington, D. C.

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The following items were discussed at this meeting:

1. The problem of defining the space flight experiments that might be required for manned guidance and control was noted. The assignment given was to prepare a survey of such experiments that might be indicated for future manned orbital and space flights.

2. Some discussion was held on the appropriate printing and distribution of the reports that have been generated from this contract. It was agreed that some of the reports would appear as NASA Contractor Reports while some did not warrant further reproduction although sufficient copies have been made available for any future requirements.

Frederick A. Muckler

Frederick A. Muckler

# M E M O R A N D U M

30 March 1965

To: Mr. S. G. Hasler

cc: Messrs. E. W. Ritter and R. W. Obermayer

From: F. A. Muckler

Subject: Contract NASw-869, Monthly Meeting No. 22, 23 March 1965

Participants: Mr. C. H. Gould, NASA Headquarters
Mr. R. Bohling, NASA Headquarters
Dr. F. A. Muckler, Bunker-Ramo

Place: The Bunker-Ramo Corp., Canoga Park, Calif.

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Based on telephone request from Mr. C. H. Gould, a preliminary report was prepared on "Manned Guidance and Control Space Flight Experiments" covering four classes of projected space flight experiments:

1. Basic research: Investigations of the human controller as affected by the space environment.

2. System design techniques: Verification of existing theory, techniques, and data in manual guidance and control.

3. System and subsystem evaluation: Studies of and evaluations of system and subsystem performance.

4. Engineering development: Verification of control-display concepts and techniques for manual guidance and control tasks.

Some 18 projected space flight experiments were tentatively described within these four main categories.

The preliminary report was submitted to NASA on 23 March 1965.

Frederick A. Muckler

Frederick A. Muckler